

The Association
of
Engineering and Shipbuilding
Draughtsmen.

GEAR MANUFACTURE.

BOOK II.—SPUR GEARS.

Detail Design.
Form Milling.
Hobbing.
Shaping.
Rack Planning.
Profile Grinding.

By F. WHITELEY.

Published by The Association of Engineering and Shipbuilding Draughtsmen,
96 St. George's Square, London, S.W.1.

SESSION 1950-51.

ADVICE TO INTENDING AUTHORS OF A.E.S.D. PRINTED PAMPHLETS.

Pamphlets submitted to the National Technical Sub-Committee for consideration with a view to publication in this series should not exceed 9,000 to 10,000 words and about 20 illustrations, making a pamphlet of about 40 to 48 pages. The aim should be the presentation of the subject clearly and concisely, avoiding digressions and redundancy. Manuscripts are to be written in the third person.

Drawings for illustrations should be done either on a good plain white paper or tracing cloth, deep black Indian ink being used. For ordinary purposes they should be made about one-and-a-half times the intended finished size, and it should be arranged that wherever possible these shall not be greater than a single full page of the pamphlet, as folded pages are objectionable, although, upon occasion, unavoidable. Where drawings are made larger, involving a greater reduction, the lines should be made slightly heavier and the printing rather larger than normal, as the greater reduction tends to make the lines appear faint and the printing excessively small in the reproduction. In the case of charts or curves set out on squared paper, either all the squares should be inked in, or the chart or curve should be retraced and the requisite squares inked in. Figures should be as self-evident as possible. Data should be presented in graphical form. Extensive tabular matter, if unavoidable, should be made into appendices.

Authors of pamphlets are requested to adhere to the standard symbols of the British Standards Institution, where lists of such standard symbols have been issued, as in the case of the electrical and other industries, and also to the *British Standard Engineering Symbols and Abbreviations*, No. 560, published by the B.S.I. in 1934 at 5/-. Attention might also be given to mathematical notation, where alternative methods exist, to ensure the minimum trouble in setting up by the printer.

The value of the pamphlet will be enhanced by stating where further information on the subject can be obtained. This should be given in the form of footnotes or a bibliography, including the name and initials of the author, title, publisher, and year of publication. When periodicals are referred to, volume and page also should be given. References should be checked carefully.

Manuscripts, in the first instance, should be submitted to the Editor, *The Draughtsman*, 96 St. George's Square, London, S.W.1.

For Pamphlets, a grant of £20 will be made to the Author, but special consideration will be given in the case of much larger pamphlets which may involve more than the usual amount of preparation.

*The Publishers accept no responsibility for the formulae or opinions
expressed in their Technical Publications.*

The Association
of
Engineering and Shipbuilding
Draughtsmen.

GEAR MANUFACTURE

BOOK II.—SPUR GEARS.

Detail Design.
Form Milling.
Hobbing
Shaping.
Rack Planning.
Profile Grinding.

By F. WHITELEY.

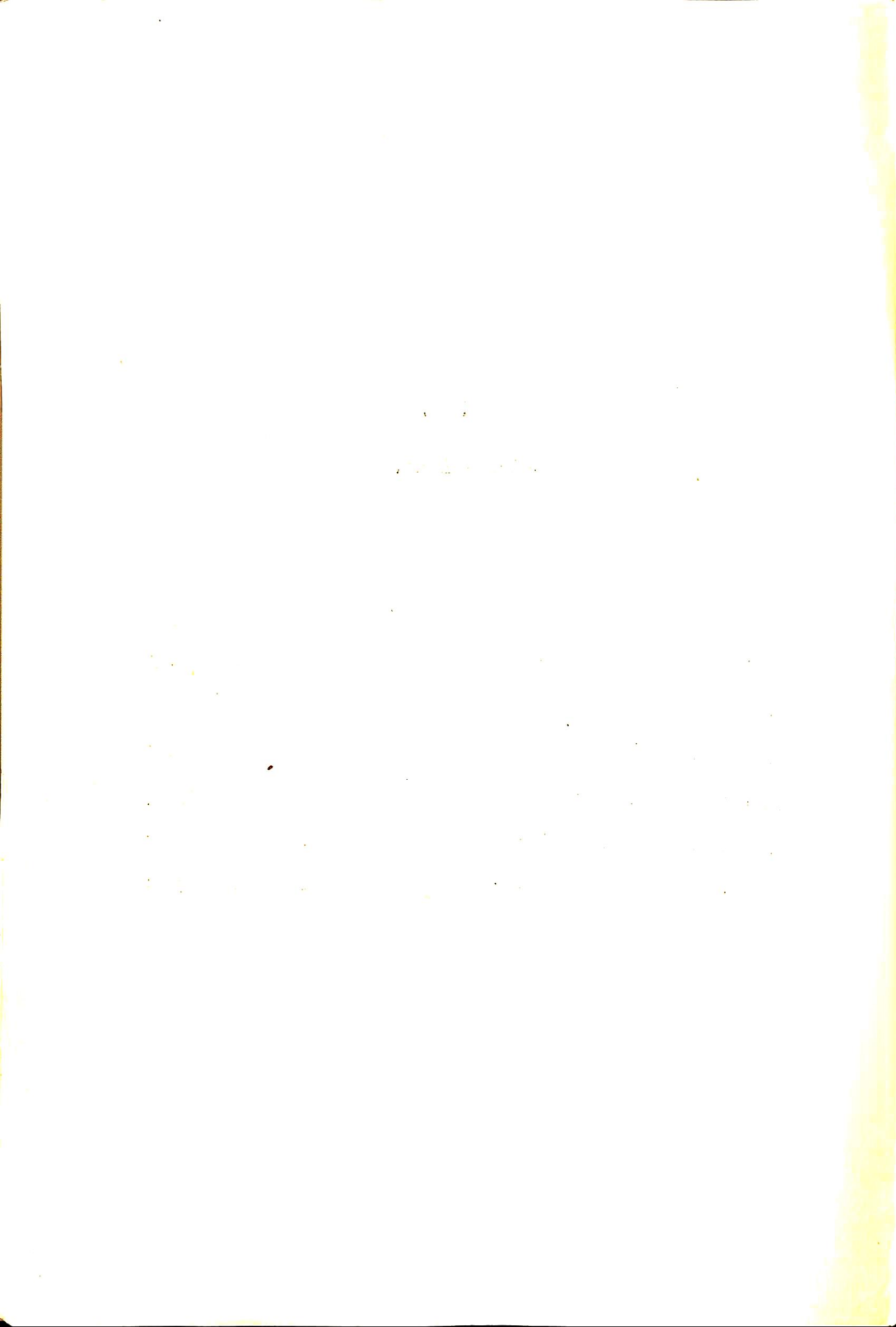
Published by The Association of Engineering and Shipbuilding Draughtsmen,
96 St. George's Square, London, S.W.1.

SESSION 1950-51.

BOOK II.
SPUR GEARS.

C O N T E N T S.

	Page
Chapter 1. Detail Design - - - - -	5-15
Chapter 2. Form Milling - - - - -	16-21
Chapter 3. Hobbing - - - - -	22-25
Chapter 4. Shaping - - - - -	26-32
Chapter 5. Rack Planing - - - - -	33-37
Chapter 6. Profile Grinding - - - - -	37-45



GEAR MANUFACTURE.

By F. WHITELEY.

CHAPTER I.

DETAIL DESIGN.

IN matters dealing with the actual manufacture of gears, it is important that the production engineer should have some knowledge of the detail design of each type of gear being produced.

At least this should apply to the gear cutting particulars given on the drawing, and as the question of materials, strength and wear which are also incorporated in the design, should be the responsibility of the designer, it is therefore not proposed to include these sections of the work in this book.

The drawing should give all relevant data required for turning, or grinding the gear blank, and cutting the gear teeth, and as shown in Fig. 1 the gear cutting particulars should be neatly tabulated for easy reference.

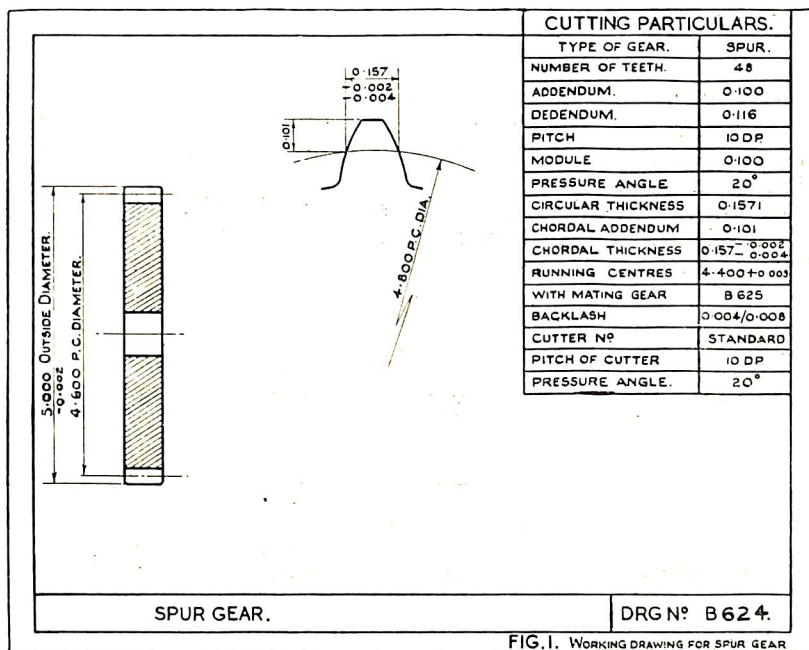


FIG.1. WORKING DRAWING FOR SPUR GEAR

The first reaction by the production engineering department on receipt of the drawing would be to ascertain if a suitable cutter is available, and in order to designate a cutter to produce the gear teeth in accordance with the particulars given, it is necessary to know if a standard cutter is available.

Standard cutters it is agreed should be used in every case for both standard and corrected gearing, and as the design department is in a position to know the pitch and pressure angle of the cutter suitable for producing the gears, to save time and trouble, the cutter data should be specified on the drawing.

Spur gears of standard proportions cannot be used for every application, and reference should be made to the chapters on correction of spur gears, when gears of standard proportions are not suitable.*

For practical purposes, however, it can be stated that all spur gears can be made with standard proportions, providing they satisfy the following conditions :—

32 teeth and over $14\frac{1}{2}^\circ$ pressure angle.

17 teeth and over 20° pressure angle.

11 teeth and over 25° pressure angle.

as in these cases the tooth flanks will be free from undercut, based

on the formula
$$Z = \frac{2}{\sin^2 \psi}$$

when Z = minimum number of teeth.

ψ = pressure angle of cutter.

Addendum and Dedendum.

The term, standard proportions, implies that the addendum and dedendum are of a recognised standard or rule, based on the pitch of the gear.

At the moment there are several standards in existence, namely, full depth involute, Fellows and British Standard, and these are listed in the table below.

<i>Standard</i>	<i>Addendum</i>	<i>Dedendum</i>	<i>Whole Depth</i>
Full Depth Involute	$\frac{1}{DP}$	$\frac{1.157}{DP}$	$\frac{2.157}{DP}$
Fellows	$\frac{1}{DP}$	$\frac{1.250}{DP}$	$\frac{2.250}{DP}$
British Standard	$\frac{1}{DP}$	$\frac{1.250}{DP}$	$\frac{2.250}{DP}$

* See Book I.

In the case of the Fellows standard the reason for the greater depth is that a circular generating cutter is used to produce the tooth form, and these cutters generate a larger fillet or radius in the root of the teeth than is the case when a rack type cutter or hob is used.

It will be noted that the depth specified for the British standard is the same as for the Fellows standard but this is due to the British standard having a greater radius specified in the root of the basic rack tooth form than is the case for the full depth involute standard, but in any case, should cutters or hobs be in existence to the full depth involute standard they should be used without being altered in accordance with the British standard.

In order to make the above remarks quite clear the basic rack tooth shapes of the various standards are shown in Fig. 2, but as a general rule it can be stated that all spur gears cut with hobs rack cutters and profile ground can be made to the full depth involute standard, while all spur gears cut with a circular generating cutter should be made to the Fellows standard.

To avoid constant duplication of cutters, lists of various types of cutters or hobs, together with their proportions should be kept for easy reference.

Pitch.—The most common term used for the pitch of spur gears nowadays is DP or diametral pitch, and the definition of this term is in words the number of teeth per inch of pitch circle diameter.

For example, taking a spur gear of 1.000 pitch diameter and having 10 teeth then the diametral pitch of this gear would be 10 DP or expressed as a formula.

$$DP = \frac{Z}{PD}$$

$$\begin{aligned} \text{When DP} &= \text{diametral pitch.} \\ Z &= \text{number of teeth.} \\ PD &= \text{pitch diameter of gear.} \end{aligned}$$

The pitch of a gear can, however, be expressed as circular pitch or module pitch, although the circular pitch is now very rarely used.

With regard to the module pitch this is most commonly used on the continent and, in fact, it has several advantages over both diametral pitch and circular pitch, especially when making calculations for pitch diameters and centre distances, the results obtained containing only whole numbers or finite decimals.

The module pitch is the reciprocal of the diametral pitch, and for a spur gear of standard proportions is also equal to the addendum thus :—

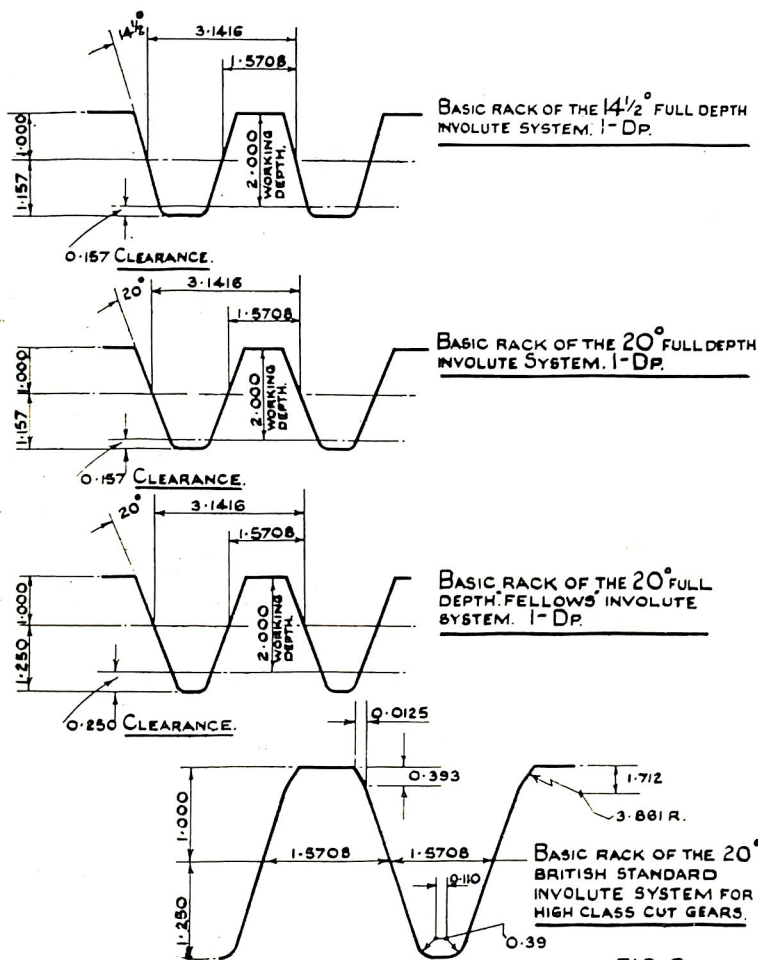


FIG. 2.

$$\text{Addendum} = \frac{1}{DP} \quad \text{and}$$

$$\text{Module} = \frac{1}{DP}$$

It will be an advantage therefore to specify the module on the gear drawing, Fig. 1, as well as the addendum, as, by so doing, it will be possible to determine whether the gear tooth is of standard proportions, by the following rules :—

- (a) If addendum of gear is equal to the module then the tooth form is of standard proportions.
- (b) If the addendum differs from the module then some modifications of tooth form has taken place.

The circular pitch is the distance measured along the circumference of the pitch circle from the centre of one tooth to another, and expressed in terms of diametral pitch we have :—

$$\begin{aligned} DP &= \pi/CP. \\ \text{When } CP &= \text{Circular Pitch.} \\ \pi &= 3.1416. \end{aligned}$$

Pressure Angle.

The pressure angle ψ for spur gears is usually made 20° in accordance with British standards, but 14° pressure angle is also used in many cases, this angle being found most suitable when correcting gears by the extended centre distance method.

The angle is arbitrary, however, and is always specified on the drawing, while for spur gears of standard proportions the cutter used should be the same pressure angle as the gear to be cut.

For correcting spur gears it is sometimes necessary to use a cutter of smaller pressure angle than the gear being cut, but in order to prove that the cutter used is suitable for the gear to be cut, a check can be made by the formula :—

$$\begin{aligned} CP \cos \psi &= CP_c \cos \psi_c \\ \text{When } CP &= \text{Circular pitch of gear to be cut.} \\ CP_c &= \text{Circular pitch of cutter.} \\ \psi &= \text{Pressure angle of gear to be cut.} \\ \psi_c &= \text{Pressure angle of cutter.} \end{aligned}$$

Backlash.

Spur gears of standard proportions are generally made with a circular tooth thickness on the pitch circle diameter, equal to half the circular pitch obtained as follows :—

$$t = \frac{\pi}{2DP}$$

When t = Circular thickness of gear tooth on pitch circle diameter.

DP = Diametral pitch.

If, however, two gears had been cut, and were required to run together at a fixed centre distance, with the tooth thickness in accordance with the above formula, it would no doubt be found that it would be impossible to assemble the two gears.

To overcome this, it would be necessary to cut the teeth slightly thinner than half the circular thickness, by cutting the teeth deeper in proportion, and thus obtain the necessary running clearance or "backlash."

The amount of backlash allowed varies of course with the pitch of the gear, and also with the purpose for which the gears are required, but for high class commercial gearing the *total backlash* between two gears should be made in accordance with the table given below.

The tolerance on the tooth thickness on each gear will, of course, be one half of the total backlash given in the table, but because of manufacturing tolerances, and changes resulting from heat treatment, it is frequently found necessary to subtract slightly more than one half of the recommended value from the theoretical tooth thickness of each member in order to obtain the correct amount of backlash on assembly :—

<i>Pitch DP</i>	<i>Minimum</i>	<i>Total Backlash Average</i>	<i>Maximum</i>
1	0.024	0.030	0.036
1.5	0.020	0.025	0.030
2	0.016	0.020	0.024
2.5	0.012	0.016	0.020
3	0.010	0.013	0.016
4	0.008	0.010	0.012
5 & 6	0.006	0.008	0.010
8 & 10	0.004	0.006	0.008
12 & 16	0.003	0.0045	0.006
Less than 16	0.002	0.003	0.004

Vernier Settings.

Vernier settings are specified on gear drawings to enable the gear teeth to be measured with a pair of gear tooth verniers, while the gear is still in position on the gear cutting machine, and this method is also used by the inspection department for gears cut to ordinary commercial limits.

For very fine limit gearing, however, a more accurate method is to place two rollers in the tooth spaces, and measure over the rollers to a previously calculated dimensions. This method is explained under "Testing of Gears."

There are, at present, two methods of calculating vernier settings for spur gear teeth:—

- (1) Pitch line settings using the chordal addendum and the chordal thickness.
- (2) Constant chord settings.

With (1) the chordal addendum and chordal thickness dimensions vary according to the number of teeth in the gears, for gears of the same pitch and proportions.

Should the second method be used, however, the same values are used for the height and thickness settings, for gears of the same pitch and pressure angle irrespective of the number of teeth in the gear.

If, therefore, constant chord settings have been specified this should be clearly stated on the drawings to avoid confusion.

To calculate pitch line settings we proceed as follows and, referring to Fig. 3, let

D	=	pitch circle diameter.
t	=	circular thickness of gear tooth.
α	=	half angle subtended by (t).
A	=	addendum of gear.
f	=	correction factor.
A_c	=	chordal addendum.
t_c	=	chordal thickness.

Then $t = \frac{\pi}{2DP}$ or value for circular thickness given on

drawing and α radians = t/D

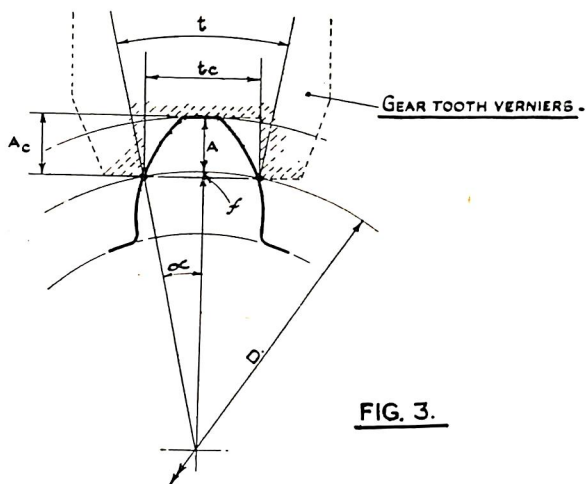
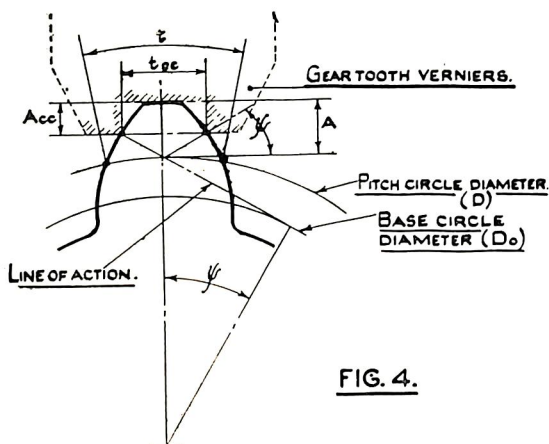
Convert α radians to degrees when one radian = 57.296 deg.

then $\sin \alpha D = t_c$.

and $f = D/2 \text{ versine } \alpha$.

then $A_c = A + f$.

From the value t_c must be deducted half the backlash tolerance given in the table and should the outside diameter be less than is specified, then the value A_c must be reduced accordingly.

FIG. 3.FIG. 4.

To avoid unnecessary calculations vernier settings for gears 1 DP, and of standard proportions are given in the table below. For other pitches the values given must be divided by the diametral pitch, after which half the backlash tolerance must be deducted from the chordal thickness.

**VERNIER SETTINGS FOR GEARS 1 DP PITCH OF
STANDARD PROPORTIONS.**

<i>No. of Teeth</i>	<i>Chordal Addendum</i>	<i>Chordal Thickness</i>	<i>No. of Teeth</i>	<i>Chordal Addendum</i>	<i>Chordal Thickness</i>
8	1.0768	1.5607	23	1.0268	1.5696
9	1.0684	1.5628	25	1.0247	1.5698
10	1.0616	1.5643	27	1.0228	1.5699
11	1.0559	1.5654	30	1.0208	1.5701
12	1.0514	1.5663	34	1.0181	1.5703
13	1.0474	1.5670	38	1.0162	1.5704
14	1.0440	1.5675	43	1.0143	1.5705
15	1.0411	1.5679	50	1.0123	1.5706
16	1.0385	1.5683	60	1.0102	1.5706
17	1.0362	1.5686	75	1.0083	1.5707
18	1.0342	1.5688	100	1.0060	1.5707
19	1.0324	1.5690	150	1.0045	1.5707
20	1.0308	1.5692	250	1.0025	1.5708
21	1.0294	1.5694	—	—	—

All spur gear teeth of the same pitch and pressure angle, irrespective of the number of teeth in the gear, are the same dimension on what is commonly known as the constant chord.

The constant chord is located on the line of action and the length of this chord is determined by the circular thickness of the tooth, as shown in Fig. 4.

To calculate the constant chord thickness and height settings, to which settings the verniers are set to measure the gear tooth, we proceed as follows :—

Referring to Fig. 4.

Let t = circular thickness of gear tooth on pitch circle diameter.

A = addendum of gear.

ψ = pressure angle of gear.

A_{cc} = constant chord height setting.

t_{cc} = constant chord thickness setting.

$$\text{Then } A_{cc} = A - \frac{t \sin 2\psi}{4}$$

$$\text{and } t_{cc} = t \cos^2 \psi.$$

Note.—For gears of 1 DP pitch 20° pressure angle

$$A_{cc} = 0.747$$

$$t_{cc} = 1.387$$

From the value t_{cc} must be deducted half the total backlash allowance, and should the outside diameter be less than is specified on the drawing the value A_{cc} must be reduced accordingly.

Centre Distance.

When D = wheel pitch diameter.

d = pinion pitch diameter.

$$\text{Then centre distance } C = \frac{D + d}{2}$$

The question of centre distance is really very important for fixed centre distance gearing as any variation will upset practically all the previously calculated dimensions.

For this reason it is preferred that the centre distance should be made slightly larger than nominal but as accurate as possible, and suggested tolerances are given below.

<i>Diametral Pitch</i>	<i>Centre Distance Tolerance</i>
16 and finer	0.000 to + 0.002
14 to 5	0.000 to + 0.003
4 to 2	0.000 to + 0.004
$1\frac{3}{4}$ to 1	0.000 to + 0.005

Example.—An example for the detail design of a spur gear of standard proportions, and having 48 teeth, 10 DP, 20° pressure angle is given below, the mating pinion having 40 teeth.

$$D = \frac{48}{10} = 4.800. \quad d = \frac{40}{10} = 4.000.$$

$$\text{Then centres } C = \frac{4.800 + 4.000}{2}$$

$$C = 4.400 + 0.003.$$

$$A = \frac{1}{10}$$

$$= 0.100$$

$$B = \frac{1.157}{10}$$

$$= 0.116 \text{ when cut to Brown \& Sharpe standard}$$

$$B = \frac{1.25}{10}$$

$$= 0.125 \text{ when cut to Fellows standard}$$

$$ht = 0.100 + 0.116 \text{ or } 0.125$$

$$= 0.216 \text{ or } 0.225$$

$$\text{Module} = \frac{1}{10}$$

$$= 0.100$$

$$p = \frac{3.1416}{10}$$

$$= 0.31416$$

$$t = \frac{3.1416}{2 \times 10}$$

$$= 0.15708$$

Vernier Settings.

$$A_c \text{ from table } \frac{1.0123}{10}$$

$$= 0.101$$

$$t_c \text{ from table } \frac{1.5706}{10}$$

$$= 0.157$$

and allowing for backlash

$$t_c = 0.157 - 0.002$$

$$= 0.004$$

To mesh with pinion 40 teeth at $4.400 + 0.003$ centres with 0.004 to 0.008 backlash.

If constant chord settings are used, then we have

$$A_{cc} = 0.100 - \frac{0.15708 \times 0.1606949}{4}$$

$$= 0.0747$$

$$t_{cc} = 0.15708 \times 0.883022$$

$$= 0.1387$$

CHAPTER II.

FORM MILLING.

Cutters.

One of the earliest methods used for producing spur gear teeth was known as the form milling method, which has been gradually superseded by the more modern and quicker method of generating the gear teeth.

For small lot production, or for change wheels having a prime number of teeth it is sometimes found necessary, however, to revert to the original method of form milling the teeth.

With this method a rotary type or endmill cutter is used, the form of the cutter being made exactly in accordance with the gear tooth space to be cut, as shown in Fig. 5.

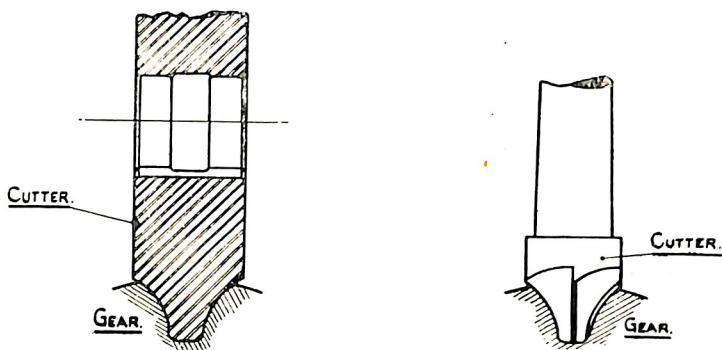


FIG. 5.

A set of eight milling cutters is required to cover the full range for each pitch, and pressure angle, the cutters being numbered 1 to 8.

No. 1 cutter	will cut teeth	135 to rack or ∞
No. 2 cutter	" "	55 to 134
No. 3 cutter	" "	35 to 54
No. 4 cutter	" "	26 to 34
No. 5 cutter	" "	21 to 25
No. 6 cutter	" "	17 to 20
No. 7 cutter	" "	14 to 16
No. 8 cutter	" "	12 to 13

Standard cutters are made $14\frac{1}{2}^\circ$ pressure angle and the cutting depth specified on the cutters as $D + f$ is equal to $\frac{2.157}{DP}$, the con-

stant of 2.157 being a constant introduced by Brown & Sharpe when they also introduced the range of cutters listed above.

Any spur gear cut with the cutters in the range will run with any other gear cut by the same system at standard centre distance, as a correction has been made to the basic rack form shown in Fig. 6 to eliminate interference, and to avoid undercutting of small pinions.

In fact it would be impossible to cut teeth with the form milling method even if undercutting of the tooth flanks was desired, therefore as metal has to be left on the tooth flanks below the base circle on small pinions, then conversely metal has to be removed from the tips of the mating gear, thus it is not possible to produce a true involute shape above the base circle.

To obtain the shape of the teeth cut by any of the cutters in the range it is necessary to generate (on the drawing board) a tooth shape corresponding to the smallest number of teeth for the cutter number selected, with the basic rack, Fig. 6.

The basic rack shape for the pitch under review is first cut out in celluloid, the pitch line of the rack being rolled round the pitch circle of the gear for which the shape is required, in a similar manner to that described in Book 1, Figs. 14, 15 and 16.

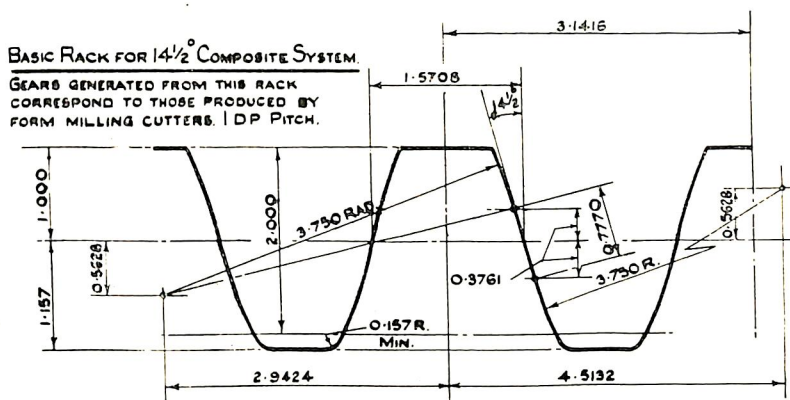


FIG. 6

Machines.—Several types of automatic machines still exist for cutting spur gears by the form milling method for gears up to 120 teeth, but in the majority of works it is found necessary to produce the gears on a milling machine using a dividing head.

In any event the gear is first mounted on a suitable arbor, and the arbor placed in the spindle of the machine, or in the case of the dividing head placed between centres.

The gear blank is checked for concentricity on the outside diameter, and should be within a clock reading of 0.001, this accuracy being necessary to ensure that the gear teeth are of uniform thickness on the pitch circle diameter.

A cutter is then obtained which corresponds to the pitch, pressure angle, and the number of teeth to be cut in the gear blank, and mounted on the cutter spindle.

The cutter should then be set exactly central with the gear blank, and checked for concentricity within a tolerance of 0.001.

The outside diameter of the gear blank is then checked for size before cutting, and any deviation from the drawing should be allowed for when setting the depth to be cut, and also when setting the chordal addendum on the gear tooth verniers.

One cut or two cuts may be necessary to completely cut each tooth space, depending, of course, on the material and/or the pitch of the teeth, but in any case the cutter should first be allowed to touch the outside diameter of the gear blank, in order to check the dividing change wheels, which are necessary to index the blank each tooth.

The cutter should then be set to cut the depth required per cut, and if completing the job in one cut the depth should be set to the value $D + f$ etched on the cutter, making allowance for any error in the machining of the outside diameter.

After completing two spaces the gear tooth should be checked with a pair of gear tooth verniers set to the chordal addendum and chordal thickness specified on the drawing, making an allowance on the chordal addendum for any variation in outside diameter.

The Dividing Head.

In order to cut the required number of teeth in the gear blank using an automatic machine the necessary change wheels are usually indicated on the chart supplied with the machine.

Should, however, the teeth be cut on a milling machine, using a dividing head, and especially if cutting a spur gear having a prime number of teeth, it may be found necessary to make a small calculation to obtain the particulars of the index change wheels.

With all universal dividing heads a set of index plates and change wheels are supplied, the index plates being used for simple indexing and the change wheels together with the index plates for differential indexing.

The index plates usually supplied have the following number of holes :—

15, 16, 17, 18, 19, 20, 21, 23, 27, 29, 31, 33, 37, 39, 41, 43, 47 and 49, while the numbers of teeth in the gears usually supplied are two off 24, and one off each 28, 32, 40, 44, 48, 56, 64, 72, 86 and 100.

To calculate the number of turns, and the number of holes, the crank lever on the dividing head must be turned. When using simple indexing we proceed as follows :—

- Let N = number of teeth to be cut.
 V = number of teeth in dividing head wormwheel = 40.
 G = number of threads in dividing head worm, usually 1.
 X = number of revolutions of crank lever to perform one division.

$$\text{Then } X = \frac{V}{N} = \frac{40}{N}$$

or in words.

To obtain a given number of divisions, divide the number of turns required for one revolution of the dividing head spindle by the number of divisions into which the periphery of the work is to be divided, for example :—

To cut a gear having 60 teeth we get

$$X = \frac{40}{60} = \frac{2}{3} \text{ revolutions of crank lever,}$$

thus the crank lever must be moved 22 holes, using the index circle of 33 holes, or to cut a gear having 32 teeth we get

$$X = \frac{40}{32} = 1\frac{5}{8} = 1\frac{4}{16} \text{ revolutions,}$$

thus the crank lever must be moved one full revolution and 4 holes using the index circle of 16 holes.

Differential Indexing.

Should it be found that by using simple indexing the required number of divisions cannot be calculated then differential indexing will have to be used.

It can be imagined that it will sometimes be necessary to index a number of divisions which necessitates a fractional turn of the crank lever, and that none of the index plates have holes which will give the fractional movement required in the manner previously described for simple indexing.

Such a fraction is one which cannot have its denominator multiplied by a common multiplier to make the denominator exactly divisible into one of the available circle of holes in the index plates.

To meet such cases differential indexing is employed.

The term differential indexing is derived from the fact that whilst the hand crank is being rotated, the index plate is also being rotated, there then being a differential movement between the crank and the plate.

As a simple case, suppose a full indexing movement of the crank handle brought the plunger pin between two holes, and there was no means of definitely holding the pin in its correct final position.

If, however, the plate was meanwhile given a movement, that one of the holes was brought definitely to the final position of the pin, that hole would serve to locate the pin accurately in its final position. Such a movement is obtained by driving the plate, whilst the crank handle is being turned through a correctly proportioned train of gears which may be simple or compound, and also may have one or two idlers.

The first driving wheel D is secured to the spindle and the final driving wheel A to a shaft which is connected by gearing to the sleeve carrying the index plate.

A quadrant is provided to carry the intermediate gears B and C and idler gears.

The method used for calculating the gear train necessary for the indexing of the required number of divisions, is first to select a circle of holes which would enable approximately the required number of divisions to be indexed by simple indexing, as previously described.

The next step is to determine a train of gears which will move the index plate in the same or opposite direction as the crank handle, to compensate for the error in the approximation.

Then let

N = number of teeth to be milled in blank.

H = number of holes in index plate circle.

n = number of holes to be used in index circle H each index.

F = approximate number of divisions chosen.

V = ratio of crank handle to spindle usually = 40.

A = gear on index plate shaft.

B & C = intermediate gears.

D = gear on spindle.

In order to explain the above method we will suppose that it is required to index for 61 divisions, and we know that 60 divisions can be obtained by simple indexing by moving the crank handle.

$$\frac{V}{F} = \frac{40}{60} = \frac{2}{3} \text{ of a turn for each division, and}$$

that any circle of holes exactly divisible by 3 can be used, *e.g.*, the 33 hole circle.

Now if the dividing head is set up to index 60 divisions using the 33 hole circle the crank handle should not be given quite a full $\frac{2}{3}$ of a turn if 61 divisions are to result.

If, however, the crank handle is moved through 22 holes of the index plate, and at the same time the plate is moved back slightly,

the crank handle will not have moved quite $\frac{2}{3}$ of a turn, and the gear train required to effect this movement can be derived from the formula :—

$$\frac{(F - N) V}{F} = \frac{\text{Driving Gears}}{\text{Driven Gears}} = \frac{D \times B}{C \times A}$$

If the result is positive it shows that the index plate must move in the same direction as the crank handle, and that no idler gear is needed in a compound train, and one idler gear is needed in a simple train.

If, however, the result is negative the plate must move in the opposite direction to the crank lever and therefore two idler pinions are needed in a simple train and one idler pinion in a compound train.

Then taking the present example 61 divisions are required but 60 divisions were taken as the approximation we get

$$\frac{(60 - 61) 40}{60} = \frac{-1 \times 40}{60} = \frac{-2}{3}$$

that is, the result is negative so that the index plate must move in the opposite direction to the crank lever and the gears are in the ratio of $\frac{2}{3}$.

Suitable gears would be a 32 tooth gear on the driving spindle D and a 48 tooth gear on the final driven shaft A, and any two idler pinions would be required between the driving and driven gears.

The change wheels are chosen as in screw cutting, a simple or compound train being selected according to the range of wheels available. The above example necessitates a simple train and as the result was negative two idler pinions are used to ensure negative rotation.

To index 293 divisions we could take 300 divisions as an approximation which would necessitate a movement of :—

$$\frac{V}{F} = \frac{40}{300} = \frac{2}{15} = 2 \text{ holes in a 15 hole circle then}$$

$$\frac{\text{Driving Gears}}{\text{Driven Gears}} = \frac{(F - N) V}{F} = \frac{(300 - 293) 40}{300} = \frac{7 \times 40}{300}$$

which is positive and shows that the index plate must turn in the same direction as the crank, so that we get

$$\frac{28}{30} = \frac{7 \times 4}{5 \times 6} = \frac{56 \times 32}{40 \times 48}$$

which being a compound train does not require an idler pinion to cause positive rotation of the index plate.

CHAPTER III.

HOBBING.

All spur gears can be hobbled, providing that there is sufficient clearance in the design of the gear to allow for the run out of the hob, and this point should be very closely watched especially if the gear to be cut has a shoulder or flange adjacent to the teeth as shown in Fig. 7.

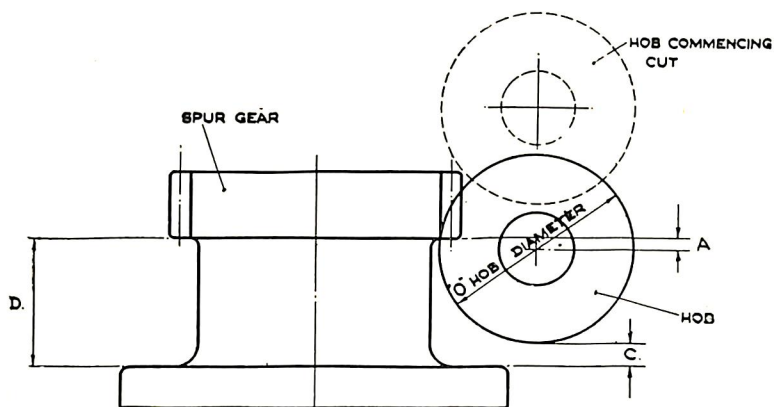
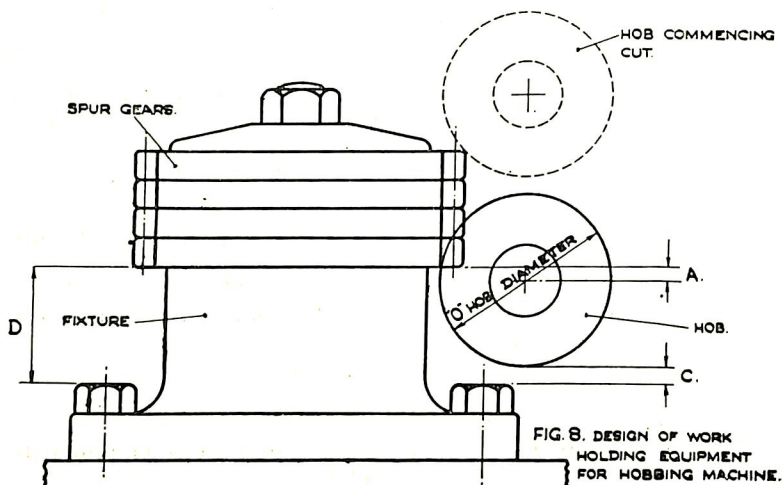


FIG. 7.

TYPICAL DESIGN OF SHOULDER
SPUR GEAR.FIG. 8. DESIGN OF WORK
HOLDING EQUIPMENT
FOR HOBBING MACHINE.

Even if the gear to be cut is of the ordinary plain type of spur gear, which is located on a mandrel for cutting, it would still be necessary to consider the run out of the hob, in this instance the necessary clearance would have to be provided when designing the work holding equipment as illustrated in Fig. 8. The question of run out (and this applies to the form milling cutter method also) is perhaps the only objection that can be found against the hobbing of spur gear teeth, and the difficulty can only be overcome by using any one of the three following methods.

1. Slotting using form slotting cutter.
2. Shaping using circular generating cutter.
3. Planing using rack generator cutter.

To determine the distance required to allow the hob to clear after cutting the teeth, the outside diameter of the hob should be known, then let

- D = distance required.
 O = outside diameter of hob.
 A = hob run out (0.125 minimum).
 C = clearance (0.25 minimum).

$$\text{Then } D = \frac{O}{2} + A + C.$$

Hobbing machines for spur gears are made with the hob swivel slide mounted on either a horizontal slide or on a vertical slide, but generally speaking there is no great advantage to be gained in either method.

The principle is the same, namely, that the work and hob are constantly rotating and their movements synchronised by means of gearing in the ratio of the number of teeth in the gear to be cut, and the number of threads in the hob.

For example for a gear in which 60 teeth have to be cut using a single thread hob, the gear will make one revolution to 60 revolutions of the hob.

If, however, a triple thread hob is used the gear would make one revolution to 20 revolutions of the hob.

Single thread hobs should, however, be used in every case for finishing, and to improve production times multiple thread hobs may be used for roughing.

Single thread hobs are more accurate than multiple thread hobs due to the fact that when manufacturing the hobs the spacing of the threads is carried out by indexing, whereas for single thread hobs no indexing is necessary, and therefore, no question of spacing errors between threads arises.

Hobs for spur gears both for roughing and finishing should be made as large as possible in diameter, but this will, of course, depend on the size of machine being used, although the maximum

diameter of hob which can be used on the machine, together with the size of the hob arbor, is usually given in the specification of the machine.

The hob is mounted on the hob arbor, and the swivel slide swung over to the helix angle of the hob to bring the hob teeth in line with the teeth to be cut, the helix angle generally being marked on the hob.

Care should also be taken to note whether the hob is made right hand or left hand helix as this will determine the direction in which the swivel slide must be set over, but all hobs for spur gears should be designed with a right hand helix, the swivel slide being swung over in the direction as shown in Fig. 9.

Change wheels for automatically indexing the work are supplied for cutting all numbers of teeth up to 120 and particulars of the wheels required for each number of teeth are given on an index gear chart, which, of course, varies with each different type of machine, depending on the ratio of the index worm and wheel.

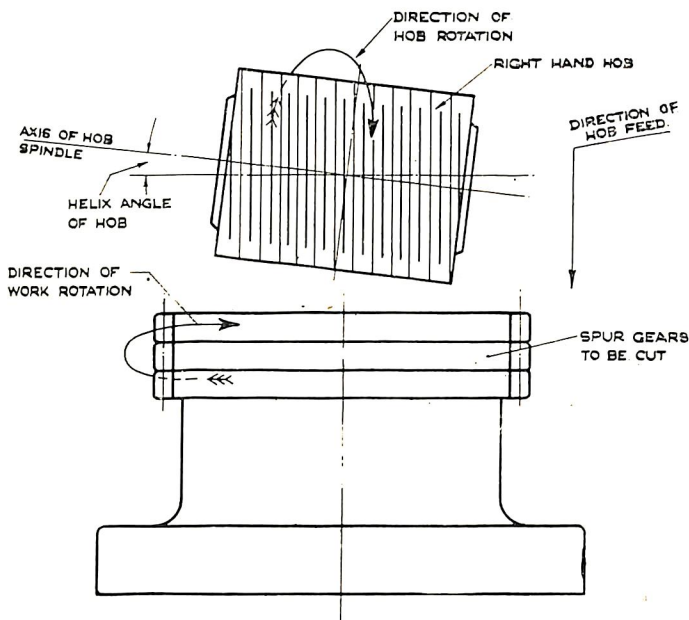


FIG 9. SHEWING DIRECTION HOB SWIVEL
SLIDE IS SWUNG OVER IN RELATION
TO WORK WHEN USING RIGHT HAND HOB

The work spindle slide is then set to cut the required tooth depth given on the drawing as addendum plus dedendum, and this also equals the value $D + f$ etched on the hob.

To set the hob slide for depth of tooth, the work should be set until a very thin strip of paper can be held between the hob and the work, and the hob allowed to just touch the blank.

As a check against a possible error in setting the index change gears, it is advisable to count the marks made by the hob on the periphery of the gear blank, and if correct, these should equal the number of teeth to be cut in the gear.

The hob slide should then be wound back, and the work head set to the tooth depth, the hob slide feed engaged and allowed to feed through the blank.

The feed selected will depend on the class of finish required, and the material being cut, and although the finish improves as the feed is decreased, the smallest possible feed by no means attains the best tooth form. In fact there is a practical limit below which the hob no longer encounters sufficient material to give it a definite hold, the accuracy of tooth form suffers, and the hob is dulled.

Finishing feeds below about 0.040 on medium pitches and 0.020 on smaller pitches bring no increased advantage.

The maximum cutting speed is limited by the capacity of the cutting edges of the hob to stand up, which naturally depends also upon the feed, the material of which the hob is made, the material being cut, and the tooth form.

If the economical cutting speed is exceeded the hob will dull quickly, and create a bad tooth form and finish, while in addition production will actually suffer as excessive cutter wear causing the removal of an undue amount at each re-sharpening brings more loss than is actually gained in cutting time.

Finishing cuts should, however, be taken at a fairly high hob speed, and a consequently proportionately reduced feed. On the other hand when roughing it is economical to use as high a feed as possible and reduce the cutting speed until the maximum feed can be employed.

When roughing it is also advisable to rough out to the finished root diameter, in order to use the finishing hob for finishing the tooth flanks only, that is, of course, when roughing and finishing are carried out separately with roughing and finishing hobs.

As a general rule, however, the speed of the hob for finishing should be within the following limits, but, of course, owing to the multiplicity of possibilities the figures can only be regarded as an average, and may be exceeded or diminished as the case may be.

Cast Iron, ...	50/80	feet per min.
Steel 40 tons maximum tensile,	80/110	" " "
Steel 40/60 tons tensile, ...	60/100	" " "
Brass or Bronze, ...	80/160	" " "
Bakelite, Tufnol, etc., ...	80/120	" " "

The difference between the higher and lower values is due to the varying tensile strength of the materials, which considerably affect the machining qualities.

CHAPTER IV.

SHAPING.

As an alternative to hobbing spur gear teeth we have the gear shaping process, originally introduced by the Fellows Gear Shaper Co., and therefore most commonly known as the Fellows process.

A circular generating cutter, Fig. 10, is used for generating the teeth and this cutter in fact represents a spur pinion, but with the addition of the necessary side and front reliefs of 6° and 5° respectively, while the cutter addendum, is made equal to the dedendum of the gear.

Due to it being necessary to have a front relief on the cutter, it is recommended that gears cut on the gear shaper should not be allowed to mesh with gears cut by any other method, as the gear shaper cutter does not produce the actual pressure angle specified.

The error is admittedly only slight, but sufficient to make all the difference between obtaining smooth running gears, especially when the gears have to run at fixed centres.

The cutter pressure angle, usually made the same as the gear to be cut is measured on the plane AA., Fig. 10, therefore due to side and front relief the actual pressure angle of the gear being cut is obtained from the formula :—

- Let ψ = pressure angle of gear being cut.
 ψ_1 = pressure angle of cutter on plane AA.
 α = side relief angle of cutter.
 θ = front relief angle of cutter.

Then

$$\tan \psi = \frac{\tan \psi_1}{\left(\frac{\cos \alpha \cos \theta}{\cos (\alpha + \theta)} \right)}$$

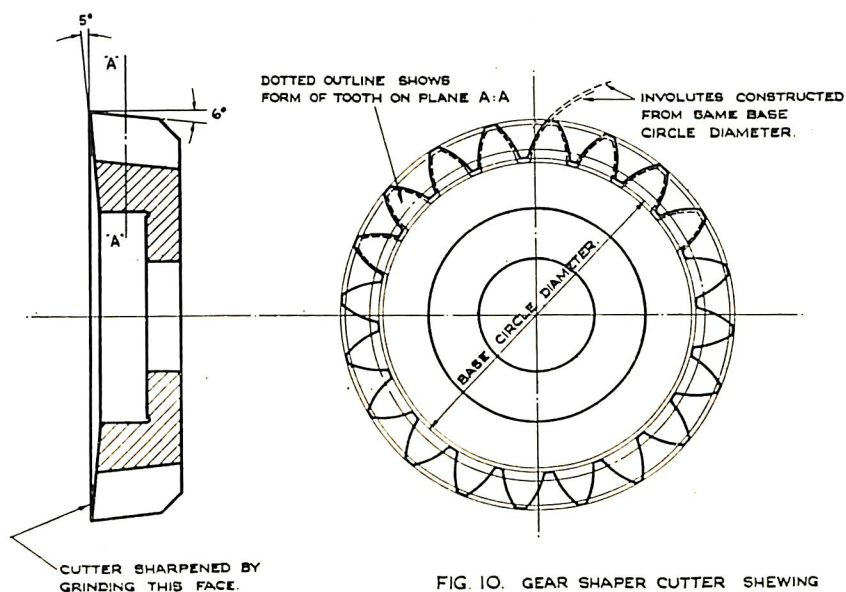


FIG. 10. GEAR SHAPER CUTTER SHEWING ACTION ON CUTTER FORM AFTER SHARPENING

For example given a gear shaper cutter of 20° pressure angle find the pressure angle of the gear to be cut.

$$\tan \psi = \frac{\tan 20^\circ}{\left(\frac{\cos 6^\circ \cos 5^\circ}{\cos (6^\circ + 5^\circ)} \right)} = \frac{0.36397}{\left(\frac{0.99452 \times 0.99619}{0.98163} \right)}$$

$$\tan \psi = 19^\circ - 50'$$

and for a cutter $14\frac{1}{2}^\circ$ pressure angle

$$\tan \psi = 14^\circ - 22'$$

It is agreed that the cutters could be made of such a pressure angle to cut gears of standard pressure angle, but as every cutter manufacturer makes the pressure angle standard on plane AA, Fig. 10, it is perhaps better to accept the position as it stands at present.

As long as the gears cut by the gear shaper method mesh together it is not of very vital importance whether the pressure angle of the gears is 20° or $19^\circ - 50'$, but when deciding upon the method of producing the gear teeth this question should be watched very closely.

The cutter is sharpened by grinding the front face only, and this in no way affects the shape of the gear tooth form being cut, except that perhaps the radii in the roots of the teeth are increased slightly, as the face of the cutter is sharpened.

Due to the 6° side relief, the cutter diameter is actually reduced as the front face is sharpened, and in Fig. 11 is shown a gear tooth being cut with a cutter of standard proportions, and in Fig. 12 is shown the same gear in relation to the cutter, after the cutter has been sharpened to plane AA, Fig. 10.

It will be noted that on Fig. 11 a pressure angle of 20° has been specified, and on Fig. 12 the pressure angle has altered slightly to $18^\circ - 9'$.

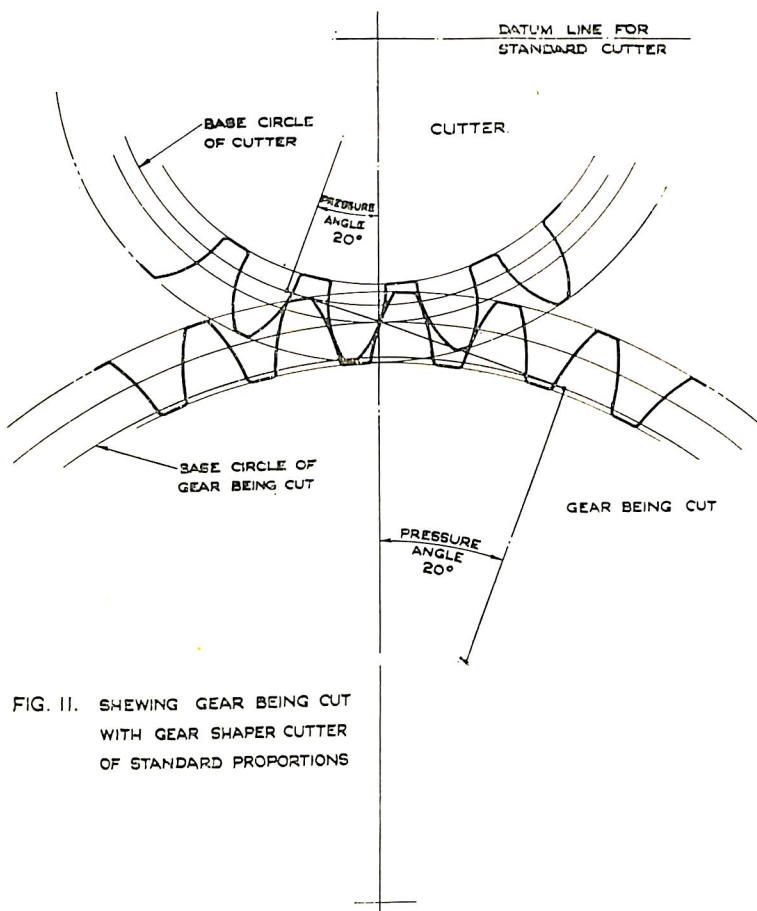


FIG. 11. SHEWING GEAR BEING CUT
WITH GEAR SHAPER CUTTER
OF STANDARD PROPORTIONS

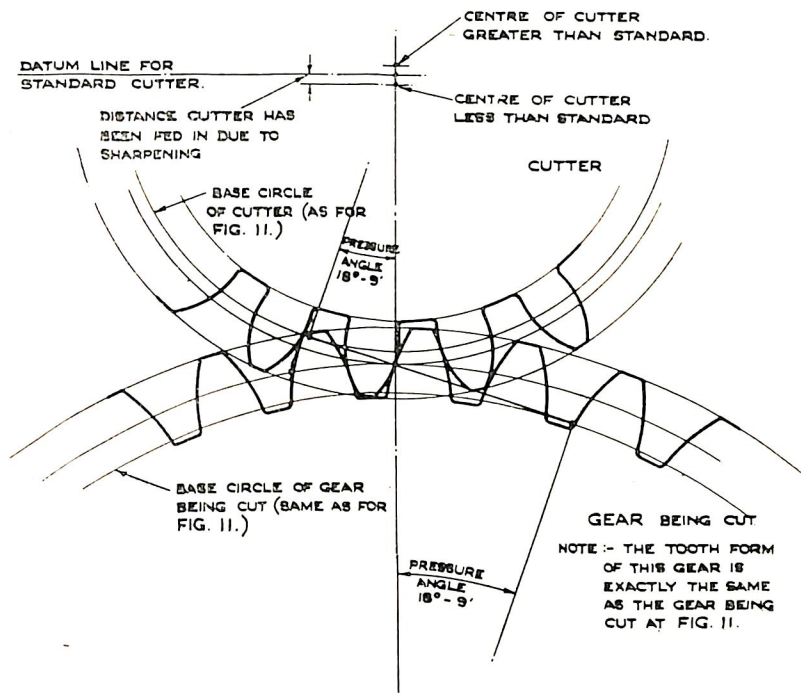


FIG. 12 SHEWING SAME GEAR AS SHEWN IN FIG. 11. BEING CUT WITH SHARPENED GEAR SHAPER CUTTER.

This pressure angle must not be confused with the pressure angle of the gear specified on the drawing. Actually it is the pressure angle of the gear at a point on a pitch circle diameter, on which the pitch of the gear teeth is the same as the pitch of the cutter teeth reduced or increased under or over a cutter diameter of standard proportions.

This cutting pressure angle although it does not affect the actual shape of the gear tooth form can be calculated as follows:—

- Let ψ = pressure angle of gear specified on drawing.
 ψ_1 = cutting pressure angle.
 C = cutting centres with cutter of standard proportions.
 C_1 = cutting centres with sharpened or oversize cutter.

Then

$$\cos \psi_1 = \frac{C \cos \psi}{C_1}$$

The base circle of the cutter does not change with sharpening therefore the same involute tooth form can be found on any transverse plane of the cutter, the teeth being simply thinner at the back than the front, and they are shortened to correspond in proportion to the side relief in order that the cutter teeth will cut a tooth space of the required depth, when fed into the gear blank to give the proper tooth thickness.

From the above reasoning, it is correct to assume that cutters could be made of the same number of teeth, but varying considerably in diameter, and yet cut teeth of the same pitch and form.

The gear shaping machine has two index drives, one for the gear to be cut, the second for the cutter, and the two movements are geared to synchronise with each other.

There is a third movement necessary for the removal of the material from the gear tooth space, *i.e.*, a reciprocating movement of the cutter ram which holds the cutter, and at the same time rotates with a continual rotary feed.

The gear blank is held on an arbor or fixture, and located in the work spindle, the whole being retained in an apron which can be unlocked when necessary, and swung outwards, to clear the cutter, in order to remove and replace the gear blanks.

This apron is provided with a relieving mechanism which withdraws the blank from the cutter on each return stroke of the cutter spindle, thus preventing the cutter from rubbing on the gear blank on the return stroke.

Two independent motions are also provided for the feed of the cutter, *i.e.*, a depth feed by which the saddle carrying the cutter is moved radially into the gear blank, and a rotary feed, as the gear blank is slowly rotated in unison.

When commencing to cut a gear the depth feed is usually engaged first and the cutter allowed to feed in about 75% of the full depth of tooth, before the rotary feed for the cutter comes into operation.

When the blank has completed one revolution, the depth feed again comes into operation automatically, the cutter being fed into the full depth of tooth, and after the blank has again completed one revolution from this point the machine stops, indicating that the gear has been completed.

When spur gears are being produced in very large quantities, it is more economical to use one or more machines for the roughing operations, and another battery of machines for finishing; in this case each operation is completed in one revolution of the gear blank, the depth feed being arranged to feed into the full depth of tooth.

To avoid excessive cutter wear on finishing cutters, it is advisable to rough cut the gear tooth slightly deeper than specified for the

finishing depth, thus leaving only the sides or flanks of the gear to be cut by the finishing cutter.

In this way, as the same cutter is not called upon to take both roughing, and finishing cuts, the finishing cutter, which takes only a light cut, will stand up much longer and produce better work.

In setting up the machine the usual precautions should be taken, namely, that the arbor, or fixture, gear blank, and cutter should be checked with a clock indicator for eccentricity.

The first step in setting up the machine is to select the cutter, and for standard spur gears this is the same pitch and pressure angle as the gear to be cut.

Two sizes of cutters are used for average work, namely, 4 inches pitch diameter for spur gears of 6 diametral pitch and coarser, and a 3 inches pitch diameter cutter for spur gears of 7 diametral pitch, and finer.

Wherever possible the cutter should work on the pull stroke, and not the push stroke, as shown in Fig. 13.

The next step is to select the necessary change gears and these depend on the number of teeth in the cutter and the number of teeth to be cut, but all this information is given on the index gear chart supplied with the machine.

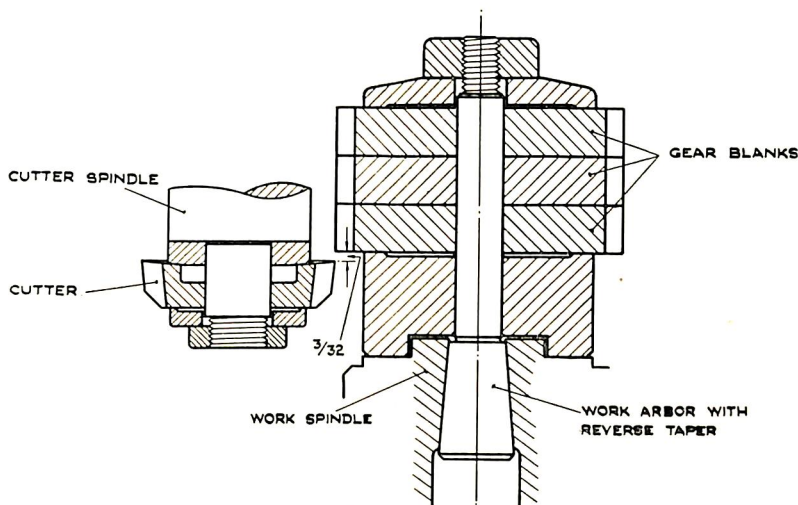


FIG. 13. SHEWING CUTTER WORKING ON PULL STROKE IN RELATION TO GEAR BLANKS

The gear blanks are then mounted on a suitable arbor, or fixture, and this should be made as robust as possible, care also being taken to see that the faces of the supporting plates are true with the bore and free from dirt.

It should also be noted especially when using arbors that the arbors for gear shapers have a reverse taper and are placed in the spindle from the lower end, therefore as the arbor cannot be drawn out of the spindle, the work can be clamped directly on the spindle flange, instead of on the arbor itself, and the tighter the work is clamped, the firmer the arbor holds.

The feed and speed levers are then set in accordance with the pitch of the gear and the materials being cut after which the stroke is set, to allow the cutter to stroke at least $\frac{3}{16}$ more than the total face width of the gears being cut, as shown in Fig. 13.

The cutter is then set in relation to the gear blank for the depth of cut, and with the saddle set in to the full depth the pitch dial is set at zero, in which case the locking pin would be in as far as it will go.

The pitch dial is set for the pitch to be cut and the stop pins are also adjusted inwards if two cuts are to be taken, the adjustment of these pins automatically setting the double cut, and the timing mechanism for stopping the machine on completion of the work.

One great advantage of the gear shaper method over the hobbing method is that gears can be cut which are very near to a shoulder, and do not require as great a distance as is required when the gears are cut by the hobbing method.

In fact spur gears of this type can be cut providing the distance from the shoulder is as low as 0.125 to 0.250, and this feature enables cluster gears to be cut without any difficulty, which would be an impossibility with the hobbing method, although the rack planning method can be just as adaptable with the provision of special tool holders.

It is advisable, however, to prepare machine layout drawings of each type and size of gear cutting machines, each drawing giving particulars of the work and cutter spindle, the relationship between the cutter spindle and work spindle, maximum and minimum pitch, and stroke, etc. It is then a simple matter to prepare tool layout drawings for each particular job as it arises.

CHAPTER V.

RACK PLANING.

A further method can be used for generating the tooth form for spur gear teeth, namely, the rack planing method.

This is very similar to the gear shaper method, excepting that where a circular gear shaper cutter is used for the gear shaper method a rack type cutter is used for the rack planing method.

The cutter is in effect a section or part of a rack, the teeth of which have cutting edges having a reciprocating motion across the face of the gear blank, parallel with the axis of the gear, thus cutting away the metal between the teeth of the gear and leaving the teeth, the cutter being gradually fed to the desired depth of tooth, after which the depth remains constant.

At the same time as this reciprocating motion is taking place in successive strokes, the blank is receiving a rotary motion, and the rack cutter traversed tangential to the pitch circle diameter of the gear, the motion of the gear blank and rack being geared to act in unison on their respective pitch lines.

This relative motion comparable to the rolling of a rack and pinion together brings new parts of the gear blank and rack into contact, and causes the teeth of the cutter to generate gear teeth of exactly the same form to gear perfectly with a rack having the same shape as the cutter.

The concerted motion of the gear blank and cutter may thus be regarded as a rolling motion, which takes place at the same time as the cutting stroke of the rack, therefore given a sufficient number of teeth in the rack cutter it would require a little more than one revolution of the gear blank to complete the gear cutting operation without any attempt to index or divide for the number of teeth being cut.

Such a long rack, which would be slightly longer than the pitch circumference of the gear being cut, would be impracticable, and therefore the gear cutting machine is arranged to index automatically, after the rolling motion has operated for a distance of one or more pitches, depending on the pitch of gear being cut.

The indexing really causing the rack cutter to "drop back" one or more teeth on the gear blank, when the rolling motion again commences. Thus, while the cutter during its cutting stroke is in contact with several teeth at the same time, it planes or shaves only a comparatively narrow strip on each tooth at each stroke, and a different part of the tooth is presented to the action of the cutter at the next stroke.

In Fig. 14 is shown a line drawing of a cutter and partly cut blank, and this shows how the tooth form is produced by the successive strokes of the cutter.

All the teeth in the gear blank, in turn, are planed in exactly the same way by the same teeth of the cutter, so that uniformity in the shape of the teeth is obtained, while all standard gears that are cut by the same cutter will mesh correctly with each other.

There are two well-known machines used for rack planing spur gears, namely, the "Sunderland" and the "Maag" but both use the same principle of operation as described above.

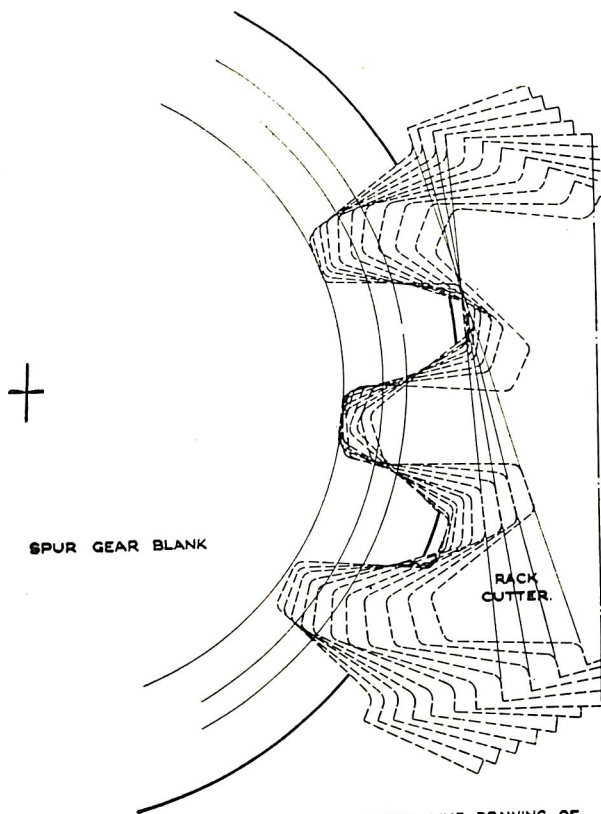


FIG. 14.

SHEWING LINE DRAWING OF CUTTER AND PARTLY MACHINED GEAR BLANK. EACH POSITION OF CUTTER IS EQUAL TO ONE STROKE OF CUTTER AFTER FEEDING IN TO DEPTH.

The difference, however, lies in the fact that the work spindle is in the horizontal plane, on the Sunderland machine, while on the Maag machine the work spindle is disposed vertically as illustrated in Figs. 15 and 16.

The indexing on the two machines is also arranged, slightly differently, but the most essential difference between the two machines is to be found in the way the cutter is mounted.

The cutter addendum is made equal to the dedendum of a spur gear of standard proportions and for rack planing this can be in accordance with the full depth involute, namely, 1.157 divided by the diametral pitch.

The only difference therefore between the cutters used on the respective machines is that while the Sunderland cutter is hollow ground, has no front rake, and the included angle of the cutter tooth is made equal to twice the pressure angle, the "Angle" of the Maag cutter tooth is slightly modified and the front face of the cutter is ground perfectly flat.

This is due to the fact that the Maag cutter is inclined at a positive angle of $6\frac{1}{2}^\circ$ when in position in the cutter box of the machine, and to allow for this the cutter is provided with a top relief of 12° while the corresponding angle on the Sunderland cutter is 6° .

When manufacturing the Maag cutter it is therefore necessary to make the pressure angle of the cutter smaller than the pressure angle of the gear to be cut, due to the $6\frac{1}{2}^\circ$ inclination, when in position, and this angle is calculated as follows:—

$$\begin{aligned}\text{Let } \psi &= \text{pressure angle of gear to be cut.} \\ \psi_c &= \text{pressure angle of Maag cutter.} \\ \theta &= \text{angle of inclination } (6\frac{1}{2}^\circ). \\ \text{Then } \psi_c &= \tan \psi \cos \theta.\end{aligned}$$

Example.—Find pressure angle of Maag cutter to cut a gear $14\frac{1}{2}^\circ$ pressure angle.

$$\begin{aligned}\text{Then } \tan \psi_c &= \tan 14\frac{1}{2}^\circ \cos 6\frac{1}{2}^\circ \\ &= 0.25862 \times 0.99357 \\ &= 14^\circ - 24' - 36''\end{aligned}$$

For standard gearing the cutter used should be the same pitch and pressure angle as the gear to be cut, while the usual precautions should be taken to ensure that the gear blanks are concentric, and that the cutter is set perfectly parallel with the cutter head slide.

The index and pitch gears should be selected in accordance with the instructions supplied with the machine, and not meshed too tight as this may cause chatter.

When cutting cluster gears or shoulder gears it may be found necessary to provide special extended cutter boxes, but these can be designed from the machine layout, which should be made available for each gear cutting machine.

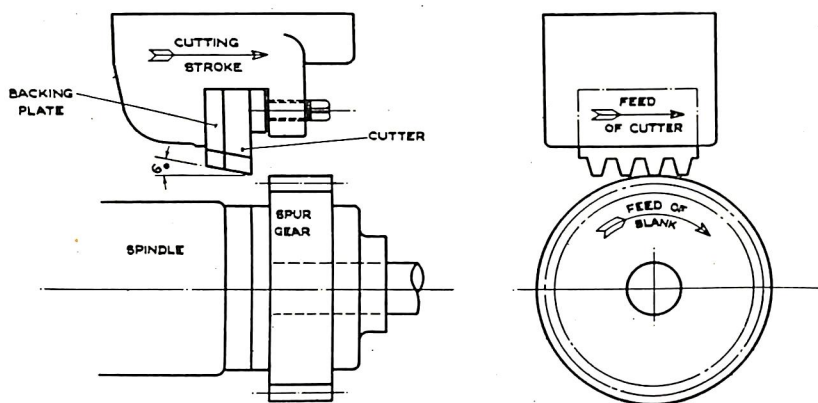


FIG. 15 SHEWING DIAGRAMMATIC VIEW OF CUTTER IN RELATION TO WORK FOR SUNDERLAND TYPE RACK TYPE PLANING MACHINE.

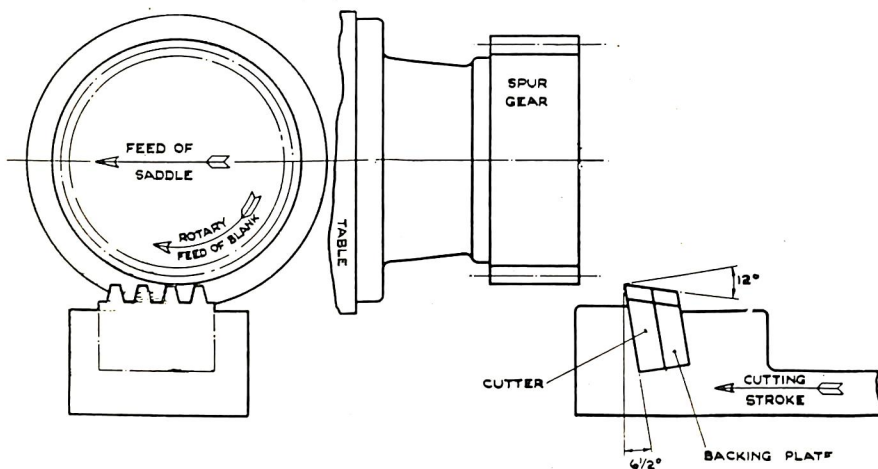


FIG. 16 SHEWING DIAGRAMMATIC VIEW OF CUTTER IN RELATION TO WORK FOR "MAAG" TYPE RACK PLANING MACHINE

Shaft gears should be held in a sleeve, and clamped firmly before attempting to cut the teeth and split type collet chucks should be avoided as much as possible.

For large gears the steady usually provided should be used to prevent chatter and possible breakage of cutters.

Double cutting is sometimes provided on the Sunderland type of rack planing machine, two cutter boxes being mounted on the reciprocating cutter slide, one cutter being arranged to cut on the ordinary cutting stroke, and the other one cutting another set of gears, suitably mounted on the arbor on the return stroke.

When cutting with a single cutter box the cutter should be arranged to cut away from the spindle, wherever possible.

CHAPTER VI.

PROFILE GRINDING.

The grinding of spur gear tooth profiles was originally introduced for hardened gears which had distorted in hardening, but has since been extended to include any gear, either heat treated or not, where accuracy and quietness in running is of first importance.

This is due to the fact that the various types of machines available for the grinding of spur gear tooth profiles, have been built to a fine degree of accuracy, and also there is less resistance to the cut when grinding than is the case when cutting, thus avoiding any possible chance of distortion of the gear, when producing the tooth form.

Two methods of grinding tooth profiles are in use at present, namely, the generating method and the form method, and although it is not the intention to advocate any particular method it is considered that while the generating method produces a more accurate involute tooth profile, greater production is obtained by using the form wheel method.

Tooth Form.

For form wheel profile grinding there are various makes of machines, but they all work on the same basic principle of using a pantagraph wheel truing device to produce the desired tooth space form from a pair of enlarged form plates.

For example, using a 6 to 1 pantagraph the effective working distance on the form plates would be six times the actual working movement of the two diamonds used to form the sides of the grinding wheel, corresponding to the gear tooth space.

Another diamond is used to trim the periphery of the grinding wheel, the position of this diamond being such that the grinding wheel will grind the correct root diameter, when the side formers are in their relative positions to give the correct tooth space width.

To do this, adjustments are provided on all three points, and it is necessary in the majority of cases to "cut and try" in order to obtain the desired tooth shape, rolling the ground gear with a master gear or rack, and observing the kind of marking thus obtained.

If the tooth flank on one side is such that the tooth space is narrow in the root, indicating that the form is what is termed "too low" the former should be lowered, and if both flanks are "too low" the work head should be lowered away from the grinding wheel.

It is advisable when obtaining the correct tooth shape to leave a small grinding allowance on the tooth flanks for removing after the shape has been obtained.

To obtain the correct tooth space width a series of rollers are usually supplied to contact the master form plate, and to leave the gear teeth thick, *i.e.*, to make the tooth space narrow a small roller is used, gradually increasing the diameters of the rollers to obtain the correct tooth space width.

The principle of the pantagraph forming mechanism is shown diagrammatically in Fig. 17, and pantagraphs can be supplied for 6 to 1 and 3 to 1 ratio, the 6 to 1 pantagraph being used for gears of 16 DP to 5 DP, and the 3 to 1 pantagraph for gears 5 DP to 2 DP pitch.

When form grinding small pinions it is not unusual to grind say an 18 tooth gear with formers suitable for $17\frac{1}{2}$ teeth, and as low as 17 teeth, while it may be necessary to use a $17\frac{1}{2}$ tooth former on one side and a $17\frac{3}{4}$ on the other.

This is due to the fact that the machine is entirely dependent on the diamond points used for trimming the sides of the grinding wheels.

If these were theoretical points and remained so, the operation of the machine would become simple, and within reason, whatever the condition of the diamond points they must be made to produce the desired shape on the grinding wheel and, of course, this is done by changing the forms.

If the gear shows a marking in both the root and tip of the tooth flank then a former plate should be used for a lower number of teeth, and if marking only in the centre a former for a higher number of teeth should be used.

This change of former is usually necessary when profile grinding small pinions, as for higher numbers of teeth the forms differ very little, and the former for the full number of teeth in the gear is generally found to be satisfactory.

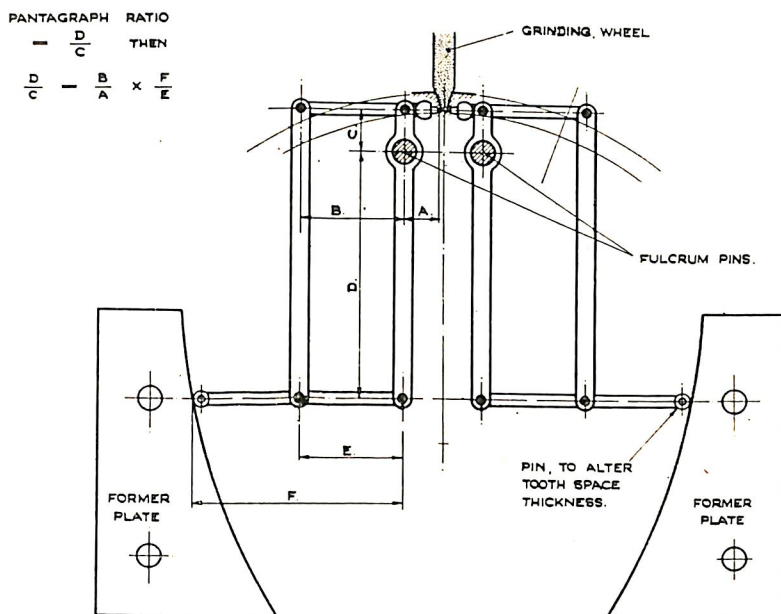


FIG. 17. SHEWING DIAGRAMMATIC VIEW OF PANTAGRAPH MECHANISM, ON FORM WHEEL PROFILE GRINDING MACHINE.

The marking to be preferred on the tooth flanks should show from near the roots of the tooth, to practically the top, within the limits of the effective working depth.

As in the case of the form milling cutter method used for cutting small spur pinions it is not practical to produce any undercut, which would be apparent if the pinions were cut by any of the generating methods, and care should be taken when designing the formers for small pinions to see that the tooth form below the base circle diameter is radial to the centre of the gear.

This rule will apply to spur pinions of standard proportions with the following characteristics :—

Under	32 teeth	$14\frac{1}{2}^\circ$	pressure angle.
"	17	20°	" "
"	11	25°	" "

When designing the formers for the mating wheel it will then, of course, be necessary to obtain the shape from the pinion by rolling or generating the wheel shape from the pinion former, as explained in Book I.

To layout a pair of formers for say a gear tooth shape without undercut, the shape of the tooth space is drawn six times the actual size of the gear tooth space to be profile ground, if using a 6 to 1 pantagraph and three times if using a 3 to 1 pantagraph.

The centre line of the tooth space should correspond to the vertical centre line of the dowel holes, as shown in Fig. 18, the two holes being used to locate the former on the gear grinding machine.

The position of the tooth shape in relation to the tooth space centre line should be measured on the pitch line diameter to a distance equal to half the circular tooth space width, times the ratio.

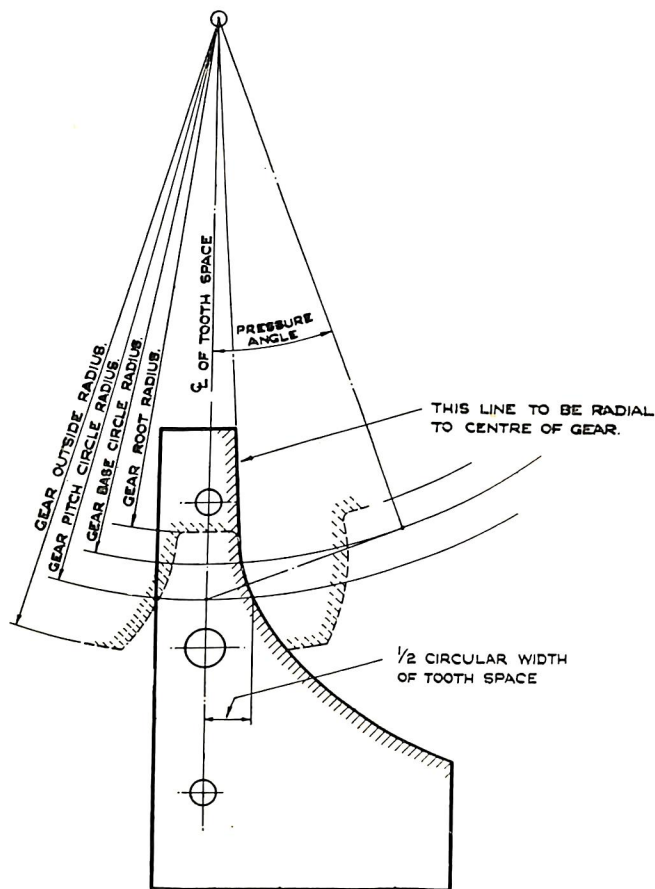


FIG 18 SHEWING LAYOUT OF FORMER
FOR FORM WHEEL PROFILE
GRINDING MACHINE

The root line diameter should be set approximately near the upper dowel hole (in figure) and after allowing for the run out both above and below the outside, and root circles respectively, the overall length of the former can be fixed.

The former shape should be set out very accurately on the theoretical shape, *i.e.*, if formers were required for 17 , $17\frac{1}{2}$ and $17\frac{3}{4}$ tooth shapes, then three sets of formers would be necessary on pitch circles corresponding to the number of teeth but of the same proportions.

Mounting of Gears.

The gear to be ground is accurately mounted on a suitable arbor, and care should be taken to see that sufficient clearance is allowed for the grinding wheel to clear the work at the end of its stroke.

To obtain this clearance, which is governed by the diameter of the grinding wheel, and the diameter of the gear to be ground, a layout should be made showing the gear blank in relation to the grinding wheel at the end of its stroke, similar to the one shown in Fig. 19.

It is also advisable to have a machine layout for each type of machine, to assist in designing work holding equipment, this drawing giving all the relevant dimensions and particulars of the dividing or index plates available.

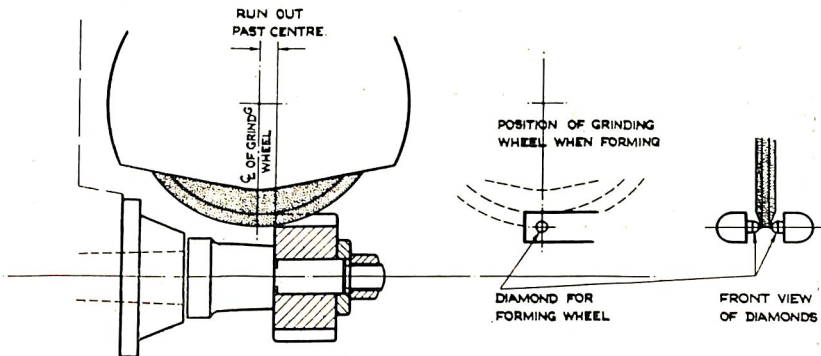


FIG. 19: SHEWING POSITION OF GRINDING WHEEL
IN RELATION TO GEAR BLANK AND
SPINDLE AT END OF STROKE.
POSITION OF GRINDING WHEEL IS ALSO
SHEWN WHEN USING FORMING ATTACHMENT

Dividing Plates.

Change gears are not used for indexing the gear blank, as greater accuracy is obtained by the use of dividing plates.

Dividing plates are supplied for all numbers of teeth up to 120 teeth, but it is not essential to provide a plate for all numbers of teeth as provision is usually made for indexing up to six notches per index on the dividing plate.

For example using a 120 tooth dividing plate, 60 teeth could be ground by indexing 2 notches, 40 teeth could be ground by indexing 3 notches, while 30 teeth could be ground by indexing 4 notches, and so on, therefore when ordering plates it is advisable to order the largest number of teeth nearest 120 teeth which is a multiple of the actual number of teeth to be ground. By so doing, a complete range of tooth numbers up to 120 will be built up very quickly, and if a chart having 120 spaces is made the tooth numbers covered by the dividing plates ordered can be filled in and thus avoid ordering more plates. When using the form wheel grinding machine, the gear blank is stationary during the actual grinding of the tooth profiles, the wheel being traversed forward and backwards once and when the wheel is clear of the work the gear blank is automatically indexed to the next tooth space, and the cycle repeated.

Generation.

The machine used when grinding tooth profiles by the generating method operates in a slightly different way.

In operation the gear rolls past the grinding wheels which have flat sides representing the basic rack, and the gear blank is slowly traversed at the same time.

When the blank is clear of the grinding wheels at the end of the stroke, the blank is automatically indexed to the next tooth, the feed reversed, grinding the tooth form on the reverse feed, and the blank is again indexed at the other end.

It is therefore necessary to provide full clearance for the grinding wheel at each end of the stroke as shown in Fig. 20, although the machine can be arranged to index the gear blank at one end only, and grind the same tooth in the forward and reverse directions.

No formers are required but instead a pitch block, Fig. 20, is used, corresponding to the pitch circle of the gear being ground, but corrected according to the inclination of the wheel head and the thickness of tapes being used.

The diameter of the pitch block plus the thickness of tape, actually corresponds to a diameter of the gear on which the pressure angle is the same as the inclination angle of the grinding wheel head, and to make the necessary calculation for the diameter of the pitch block D_p .

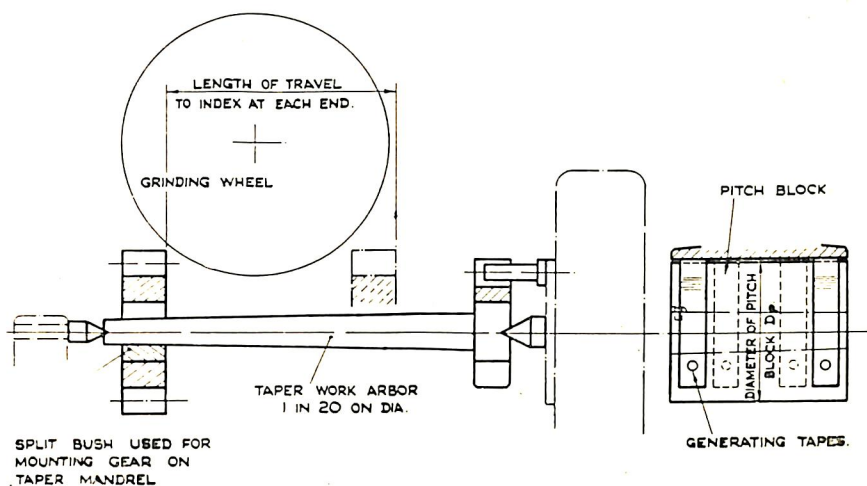


FIG. 20. SHEWING POSITION OF WORK WHEN GRINDING TOOTH PROFILES ON 'MAAG' SPUR GEAR PROFILE GRINDING MACHINE.

Let D = pitch diameter of gear being ground.
 ψ = pressure angle of gear.
 θ = inclination of grinding wheel head.
 D_p = diameter of pitch block.
 Y = thickness of tape.

$$\text{Then } D_p = \frac{D \cos \psi}{\cos \theta} - Y$$

The inclination angle θ of the grinding wheel head varies of course with the type of machine being used, but for the Maag machine, on which two opposed wheels are used, as shown in Fig. 21, the inclination angle is 15° and the tape thickness 0.008 for pitch blocks up to 4.000 diameter, and 0.012 above this diameter.

Other dimensions required for manufacturing the pitch blocks vary with the size and type of machine being used, while the angle α in figure also varies according to the diameter of the pitch block, although full details for producing the pitch blocks are usually supplied with each machine by the makers.

It will be noted that the pitch blocks are provided with a taper bore, and the same method is recommended for mounting the work on the work spindle, as it is then not essential to machine the end faces of the gear blank exactly square with the bore, as would be the case if the gear blanks were mounted on a parallel arbor, and clamping plates used for securing the blank.

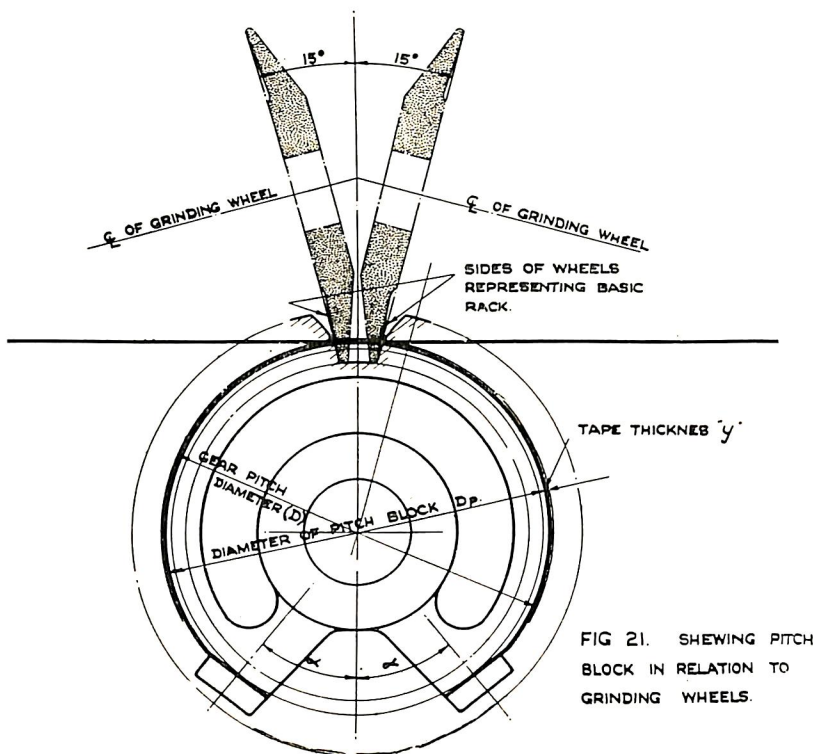


FIG 21. SHEWING PITCH BLOCK IN RELATION TO GRINDING WHEELS.

The dividing plates can be indexed one, two, three or four notches as was the case for the form wheel grinding index plates, thus avoiding having to keep in stock index plates for all numbers of teeth up to 120.

On the Maag machine the grinding wheels are automatically trimmed when the wheels are actually grinding the tooth profiles and it will be noted that the sides of the wheels are slightly undercut so that the points of the wheels are utilised for grinding the tooth flanks, the effect of this being to produce a "cross hatch" finish which is entirely different to the finish obtained by the form wheel method of grinding.

All spur gears which require to be ground on the tooth profiles should first be provided with a good accurate bore, or centres, which are then used for grinding the outside diameter to a fairly close tolerance to finished drawing size.

The same location should then be used for grinding the tooth profiles, thus ensuring that the outside diameter and the teeth are concentric with each other.

It is not advisable to grind the root diameter of the gear as the teeth should be cut of such a depth to provide the required clearance, but, of course, it is sometimes necessary, especially in the case of aircraft gearing, to clean up the root diameter to enable the inspection department to test for cracks.

When cutting gear teeth therefore which have to be profile ground at a later operation it is important to know if grinding in the roots is necessary or not, and, if so, a minimum amount of material should be left in the roots at the cutting operation.

A grinding allowance must be left on the tooth thickness, the amount varying according to the pitch and the material of the gear in question, but for average work it is considered that an allowance of 0.010/0.012 on the tooth thickness, *i.e.*, 0.005/C.006 on each tooth flank will cover any contingencies such as distortion or eccentricity, etc., should they arise.

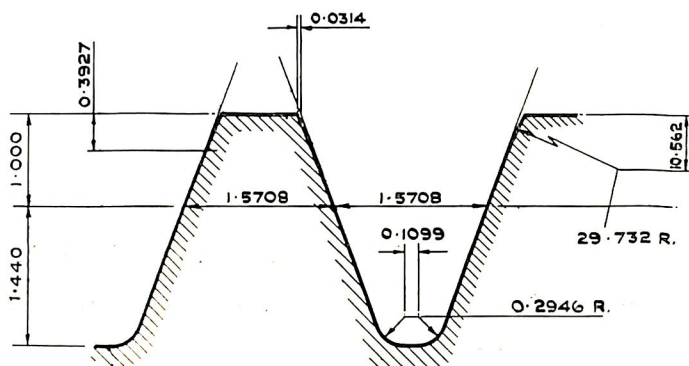


Fig. 22.

BASIC RACK TOOTH OF THE 20°
BRITISH STANDARD INVOLUTE SYSTEM
FOR PRECISION GROUND SPUR GEARS.
1 - DP

The British Standard basic rack tooth for profile ground spur gears is shown in Fig. 22, and it will be noted that the depth of tooth has been increased considerably, although it is claimed that as the radii in the roots of the teeth have been increased accordingly, the tooth is actually stronger than a tooth cut to the full involute depth standard.

This in no way affects the question of gear grinding, however, excepting that it again stresses the importance of including all the necessary dimensions on the gear drawing for the works to produce the gear teeth to the dimensions given.

A.E.S.D. Printed Pamphlets and Other Publications in Stock.

An up-to-date list of A.E.S.D. pamphlets in stock is obtainable on application to the Editor, *The Draughtsman*, 96 St. George's Square, London, S.W.1.

A similar list is also published in *The Draughtsman* twice a year.

Readers are asked to consult this list before ordering pamphlets published in previous sessions.

List of A.E.S.D. Data Sheets.

1. Safe Load on Machine-Cut Spur Gears.
2. Deflection of Shafts and Beams.
3. Deflection of Shafts and Beams (Instruction Sheet).
4. Steam Radiation Heating Chart.
5. Horse-Power of Leather Belts, etc.
6. Automobile Brakes (Axle Brakes).
7. Automobile Brakes (Transmission Brakes).
8. Capacities of Bucket Elevators.
9. Valley Angle Chart for Hoppers and Chutes.
10. Shafts up to 5½-in. diameter, subjected to Twisting and Combined Bending and Twisting.
11. Shafts, 5¾ to 26 inch diameter, subjected to Twisting and Combined Bending and Twisting.
12. Ship Derrick Booms.
13. Spiral Springs (Diameter of Round or Square Wire).
14. Spiral Springs (Compression).
15. Automobile Clutches (Cone Clutches).
16. " " (Plate Clutches).
17. Coil Friction for Belts, etc.
18. Internal Expanding Brakes. Self-Balancing Brake Shoes (Force Diagram).
19. Internal Expanding Brakes. Angular Proportions for Self-Balancing.
20. Referred Mean Pressure Cut-Off, etc.
21. Particulars for Balata Belt Drives.
22. 7/8" Square Duralumin Tubes as Struts.
23. 1" " " " " " (30 ton yield).
24. 3/4" Sq. Steel Tubes as Struts (30 ton yield).
25. 7/8" " " " " " (30 ton yield).
26. 1" " " " " " (30 ton yield).
27. 3/4" " " " " " (40 ton yield).
28. 7/8" " " " " " (40 ton yield).
29. 1" " " " " " (40 ton yield).
30. Moments of Inertia of Built-up Sections (Tables).
31. Moments of Inertia of Built-up Sections (Instructions and Examples).
32. Reinforced Concrete Slabs (Line Chart).
33. Reinforced Concrete Slabs (Instructions and Examples).
34. Capacity and Speed Chart for Troughed Band Conveyors.
35. Screw Propeller Design (Sheet 1, Diameter Chart).
36. " " " (Sheet 2, Pitch Chart).
37. " " " (Sheet 3, Notes and Examples).
38. Open Coil Conical Springs.
39. Close Coil Conical Springs.
40. Trajectory Described by Belt Conveyors (Revised 1949),
41. Metric Equivalents.
42. Useful Conversion Factors.
43. Torsion of Non-Circular Shafts.
44. Railway Vehicles on Curves.
45. Chart of R.S. Angle Purlins.
46. Coned Plate Development.
47. Solution of Triangles (Sheet 1, Right Angles).
48. Solution of Triangles (Sheet 2, Oblique Angles).
49. Relation between Length, Linear Movement and Angular Movement of Lever (Diagram and Notes).
50. " " " " " " (Chart).
51. Helix Angle and Efficiency of Screws and Worms. "
52. Approximate Radius of Gyration of Various Sections.

53. Helical Spring Graphs (Round Wire). }
54. " " " (Round Wire). Connected.
55. " " " (Square Wire).
56. Relative Value of Welds to Rivets.
57. Ratio of Length/Depth of Girders for Stiffness.
58. Graphs for Strength of Rectangular Flat Plates of Uniform Thickness.
59. Graphs for Deflection of Rectangular Flat Plates of Uniform Thickness.
60. Moment of Resistance of Reinforced Concrete Beams.
61. Deflection of Leaf Spring.
62. Strength of Leaf Spring.
63. Chart Showing Relationship of Various Hardness Tests.
64. Shaft Horse Power and Proportions of Worm Gear.
65. Ring with Uniform Internal Load (Tangential Strain) }
66. Ring with Uniform Internal Load (Tangential Stress) Connected.
67. Hub Pressed on to Steel Shaft. (Maximum Tangential Stress at Bore of Hub). }
68. Hub Pressed on to Steel Shaft. (Radial Gripping Pressure between Hub and Shaft).
69. Rotating Disc (Steel) Tangential Strain. }
70. " " " Stress. Connected.
71. Ring with Uniform External Load, Tangential Strain. }
72. " " " Stress. Connected.
73. Viscosity Temperature Chart for "Converting" Commercial to Absolute Viscosities. }
74. Journal Friction on Bearings. Connected.
75. Ring Oil Bearings.
76. Shearing and Bearing Values for High Tensile Structural Steel Shop Rivets, in accordance with B.S.S. No. 548/1934. }
77. Permissible Compressive Stresses for High Tensile Structural Steel, manufactured in accordance with B.S.S. 548/1934. Connected.
78. Velocity of Flow in Pipes for a Given Delivery. }
79. Delivery of Water in Pipes for a Given Head. Connected.
80. Working Loads in Mild Steel Pillar Shafts.
81. Involute Toothed Gearing Chart.
82. Steam Pipe Design. Chart Showing Flow of Steam Through Pipes.
83. Variation of Suction Lift and Temperature for Centrifugal Pumps.
84. Nomograph for Uniformly Distributed Loads on British Standard Beams.
85. " " " " " " }
86. " " " " " " Connected.
87. Notes on Beam Design and on Use of Data Sheets, Nos. 84-5-6. }
88. " " " " " " }
89. Curve "Relating" Natural "Frequency" and Deflection. Connected.
90. Vibration Transmissibility Curved or Elastic Suspension.
91. Instructions and Examples in the Use of Data Sheets, Nos. 89 and 90.
92. Pressure on Sides of Bunker.
- 93-4-5-6-7. Rolled Steel Sections.
- 98-99-100. Boiler Safety Valves.
101. Nomograph Chart for Working Stresses in Mild Steel Columns.
102. Pressure Required for Blanking and Piercing.
103. Punch and Die Clearances for Blanking and Piercing.
104. Nomograph for Valley Angles of Hoppers and Chutes.

(Data Sheets are 2d to Members, 4d to others, post free).

Orders for Pamphlets and Data Sheets to be sent to the Editor,
The Draughtsman, cheques and orders being crossed "A.E.S.D."

